

## Comparative Efficacy of the Maze Procedure for Restoration of Atrial Contraction in Patients With and Without Giant Left Atrium Associated With Mitral Valve Disease

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**Objectives.** We sought to determine the effectiveness of the maze procedure for restoring atrial contraction in patients with and without giant left atrium (GLA).

**Background.** Although the maze procedure has been reported to be effective for refractory atrial fibrillation, it is unknown whether this procedure can restore effective atrial contraction in patients with GLA.

**Methods.** Nineteen patients with and 32 patients without GLA were studied with Doppler echocardiography before and after the maze procedure. Peak velocity and the time-velocity integral of the left ventricular diastolic filling wave during atrial contraction (A wave) and the atrial filling fraction calculated as the ratio of the time-velocity integral of the A wave to that of total diastolic filling were compared between patients with and without GLA. A peak A wave velocity  $\geq 10$  cm/s was considered to indicate echocardiographic evidence of effective atrial contraction.

**Results.** Regular rhythm with P waves was restored in 10 patients (53%) with and 26 (81%,  $p < 0.05$ ) without GLA. Four patients (21%) with and 21 patients (66%,  $p < 0.01$ ) without GLA showed effective atrial contraction by echocardiography. Once atrial contraction was resumed, the degree of atrial contraction was comparable between patients with and without GLA ( $17 \pm 5\%$  vs.  $17 \pm 4\%$  for atrial filling fraction at 12 months, respectively).

**Conclusions.** Although most patients without GLA had restored atrial contraction by the maze procedure, it was resumed in fewer patients with GLA. However, once atrial contraction was resumed, the degree of atrial contraction was comparable between patients with and without GLA. Therefore, the maze procedure may be an option in selected patients with GLA.

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Atrial fibrillation (AF) is the most common of all cardiac arrhythmias. It not only increases the risk of thromboembolism but also may disturb hemodynamic conditions, with loss of atrial pump function, particularly in patients with associated cardiac diseases. Furthermore, patients with AF are often extremely symptomatic, requiring medical or electrical cardioversion. AF has been shown to be associated with left atrial enlargement (1), and this chamber dilation itself is considered to contribute to the persistence of AF (2). Therefore, AF with a large left atrium is refractory to conventional cardioversion (3).

An extreme example of a large left atrium is called giant left atrium (GLA), which has been recognized as significantly morbid in patients with mitral valve disease and AF (4,5). GLA is not simply a severely dilated left atrium; its abnormal

pathophysiologic features affect the surrounding organs. GLA induces respiratory dysfunction by compression of the left main bronchus or the middle and lower lobes of the right lung. More importantly, it induces hemodynamic disturbances by compression of the posterobasal portion of the left ventricular wall toward the interventricular septum (4). Thus, reduction of atrial size by plication and efforts to resume sinus rhythm are concomitantly performed with mitral valve surgery (5).

Recently, Cox et al. (6) designed the maze procedure as a surgical treatment for patients with AF in whom conventional medical therapy has failed. Kosakai et al. (7) have reported a modified maze procedure and proved its safety and efficacy in patients with chronic AF associated with mitral valve disease. There have been several other reports regarding the efficacy of the maze procedure for refractory AF (8,9). However, no reports have focused on the effect of this procedure on patients with GLA. Also, most previous studies have focused mainly on whether the maze procedure could restore regular rhythm on the electrocardiogram (ECG), and few studies have mentioned restoration of effective atrial contraction after the maze procedure (7,10-13). In the present study, we determined the effectiveness of the maze procedure for restoring effective atrial contraction in patients with AF with and without GLA.

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**Abbreviations and Acronyms**

AF = atrial fibrillation

ECG = electrocardiogram, electrocardiographic

GLA = giant left atrium

**Methods**

**Definition of GLA.** According to the definition of GLA of Beppu et al. (4) and Kawazoe et al. (5), we defined GLA as follows: 1) an extremely large left atrium depicted by M-mode and B-mode echocardiograms (left atrial diameter  $\geq 65$  mm on M-mode echocardiogram); and 2) a left ventricular posterobasal wall bent inward and lying between the dilated left atrial cavity and the left ventricular cavity, with a posterobasal segment that bends  $>30$  mm in the long-axis view on the B-mode echocardiogram immediately after the onset of diastole (Fig. 1).

**Patient group.** Between February 1992 and August 1995, a total of 180 patients underwent a modified maze procedure simultaneously with open heart surgery for refractory AF and underlying organic lesions. Nineteen patients (11%) had GLA (GLA group: 8 men, 11 women; mean  $\pm$ SD] age  $57 \pm 11$  years, range 30 to 70) and underwent operation during the late phase of the time period when the results of the maze procedure were stable. All patients had mitral valve disease and chronic AF defined as AF lasting  $>6$  months. Three patients had mitral stenosis, nine had mitral regurgitation, and seven had both mitral stenosis and regurgitation. The modified maze procedure was simultaneously performed with mitral valve surgery (n = 19), aortic valve surgery (n = 3), tricuspid annuloplasty (n = 7) and left atrial plication (n = 8) (Table 1).

From the same study group, 32 consecutive patients with mitral valve disease without GLA were selected as the control group (14 men, 18 women; mean age  $59 \pm 8$  years, range 43 to 70). To avoid the “learning curve effect” of the maze procedure, they were selected from the patients who were operated on during the same period as those with GLA. All patients had mitral valve disease and chronic AF. Fifteen patients had mitral stenosis, 8 had mitral regurgitation and 9 had both mitral stenosis and regurgitation. Concomitant procedures included mitral valve surgery (n = 32), aortic valve surgery (n = 17), tricuspid annuloplasty (n = 13) and coronary artery bypass graft surgery (n = 2). The control group had a higher

**Table 1.** Patient Characteristics

	GLA Group (n = 19)	Control Group (n = 32)
Mean age (yr)	57 $\pm$ 11	59 $\pm$ 8
Men/women	8/11	14/18
Chronic AF	19 (100%)	32 (100%)
Duration of AF (yr)	11 $\pm$ 7*	6 $\pm$ 6
Mitral valve disease		
MS	3 (16%)†	15 (47%)
MR	9 (47%)	8 (25%)
MSR	7 (37%)	9 (28%)
Additional procedure		
MVR	11 (58%)	22 (69%)
MVP	6 (32%)	6 (19%)
OMC	2 (11%)	4 (13%)
AVR	2 (11%)*	15 (47%)
AVP	1 (5%)	2 (6%)
TAP	7 (37%)	13 (41%)
LAP	8 (42%)*	0
CABG	0	2 (6%)

\*p < 0.01, †p < 0.05 versus control group. Data presented are mean value  $\pm$  SD or number (%) of patients. AF = atrial fibrillation; AVP = aortic valvuloplasty; GLA = giant left atrium; AVR = aortic valve replacement; CABG = coronary artery bypass graft surgery; LAP = left atrial plication; MR = mitral regurgitation; MS = mitral stenosis; MSR = mitral stenosis and regurgitation; MVP = mitral valvuloplasty; MVR = mitral valve replacement; OMC = open mitral commissurotomy; TAP = tricuspid annuloplasty.

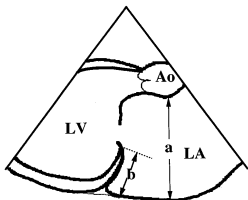
incidence of mitral stenosis and aortic valve replacement. In the GLA group, the duration of AF was significantly longer than that in the control group (Table 1). We excluded patients with reoperation from the study.

**Maze procedure.** We have modified the maze procedure originated by Cox et al. (6). Details of the procedure we performed have been reported elsewhere (7). The major modifications include changes in atriotomy lines, aiming at preserving sinus node arteries, and usage of cryoablation instead of atriotomy and reanastomosis to simplify the procedure. Other modifications are transection of the superior vena cava and detachment of the left ventricle at the circumferential left atriotomy around the pulmonary veins to improve exposure and manipulation of the mitral valve.

**ECG findings.** A standard 12-lead ECG was recorded in all patients during their regular visit to our hospital, which was once a month after discharge. The recordings at 1, 3, 6 and 12 months after the operation were analyzed to determine cardiac rhythm and the presence or absence of electrical atrial activity (P waves).

**Ultrasound examination.** Ultrasound examinations were performed with a commercially available ultrasound system (SSD 870, Aloka, Tokyo, Japan; SSH-160A, Toshiba, Tokyo, Japan; or Sonos 2000, Hewlett-Packard) using a 2.5-MHz imaging transducer before ( $1.9 \pm 4.5$  months) and 1 (n = 44), 3 (n = 34), 6 (n = 33) and 12 months (n = 41) after the procedure. Left atrial diameter was measured at the time of aortic valve closure on the M-mode echocardiogram in the parasternal long-axis view. End-diastolic and end-systolic in-

**Figure 1.** Schema of GLA. Left atrial diameter (a) is  $\geq 65$  mm, and the length of the segment bending inward (b) is  $>30$  mm. Ao = aorta; LA = left atrium; LV = left ventricle.



**Table 2.** Comparison of Echocardiographic Variables Between Giant Left Atrium and Control Group Before and After Maze Procedure

	Before	1 mo	3 mo	6 mo	12 mo
GLA group (n = 19)					
Left atrial diameter (cm)	7.3 ± 1.4*	5.3 ± 0.9*‡	5.2 ± 0.8*‡	5.2 ± 0.7*‡	5.4 ± 1.0*‡
LV end-diastolic diameter (cm)	5.8 ± 0.8†	4.6 ± 0.4‡	4.8 ± 0.5‡	4.8 ± 0.4‡	4.8 ± 0.4‡
LV end-systolic diameter (cm)	3.7 ± 0.6†	3.2 ± 0.6§	3.3 ± 0.7	3.4 ± 0.5	3.2 ± 0.5‡
Fractional shortening (%)	36 ± 8	30 ± 10§	33 ± 10	31 ± 7	34 ± 9
Control group (n = 32)					
Left atrial diameter (cm)	5.5 ± 0.8	4.6 ± 0.5‡	4.5 ± 0.5‡	4.6 ± 0.4‡	4.8 ± 0.6‡
LV end-diastolic diameter (cm)	5.2 ± 0.9	4.4 ± 0.5‡	4.5 ± 0.6‡	4.6 ± 0.5‡	4.6 ± 0.5‡
LV end-systolic diameter (cm)	3.3 ± 0.6	3.0 ± 0.5‡	3.1 ± 0.5	3.1 ± 0.5	2.9 ± 0.4‡
Fractional shortening (%)	35 ± 7	30 ± 7§	31 ± 7	34 ± 8	35 ± 5

\*p < 0.01, †p < 0.05 versus control group. ‡p < 0.01, §p < 0.05 versus before maze procedure. Data presented are mean value ± SD. GLA = giant left atrium; LV = left ventricular.

ternal left ventricular diameters were determined from the M-mode echocardiogram of the left ventricle, and fractional shortening was obtained.

Transmitral flow velocity was measured with pulsed Doppler echocardiography, with a sample volume positioned at the level of the mitral tip in the apical four-chamber view and was recorded on a stripchart at a paper speed of 100 mm/s. Peak velocity and the time-velocity integral of the late filling wave (A wave) were determined. When the deceleration line of early filling wave did not reach the baseline, the time-velocity integral of the A wave was measured as an area above the extrapolation line of early filling wave deceleration. Atrial filling fraction was derived as the ratio of the time velocity integral of the A wave to that of total diastolic filling. Each measurement was obtained as an average of 6 to 8 consecutive beats. We arbitrarily considered that an A wave peak velocity ≥10 cm/s indicated echocardiographic evidence of effective atrial contraction. Data were analyzed by an observer (S.Y.) who had no knowledge of clinical and patient information.

**Statistical analysis.** Results are expressed as mean value ± SD. Chi-square analysis was used to assess differences of the incidence of persistent AF between the GLA group and the control group. The Student unpaired *t* test was used to determine the significance of the difference of continuous variables between the two groups. M-mode and Doppler echocardiographic variables during the study period were assessed by multiple comparison analysis (one-way analysis of variance, followed by the Scheffé test). We considered results significant at *p* < 0.05.

## Results

### Ultrasound variables before and after the maze procedure.

Before the maze procedure, left atrial and left ventricular end-diastolic and end-systolic diameters were significantly larger in the GLA group than in the control group (7.3 ± 1.4 vs. 5.5 ± 0.8 cm, *p* < 0.01 for left atrial diameter; 5.8 ± 0.8 vs. 5.2 ± 0.9 cm, *p* < 0.05 for left ventricular diastolic diameter; 3.7 ± 0.6 vs. 3.3 ± 0.6 cm, *p* < 0.05 for left ventricular systolic

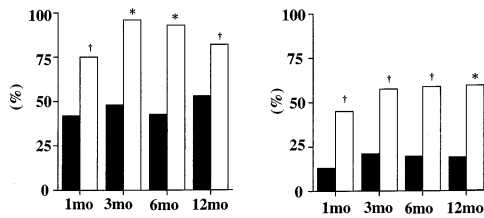
diameter). However, fractional shortening was not significantly different between the two groups (Table 2).

After the procedure, left atrial and ventricular end-diastolic diameters significantly decreased and did not change thereafter in both groups. Left ventricular end-systolic diameter also decreased, with statistical significance at 1 and 12 months. Fractional shortening decreased transiently at 1 month but did not show significant changes after 3 months compared with preprocedural values. Left atrial diameters were significantly larger in the GLA group than in the control group throughout the study period (Table 2).

**ECG findings.** In the GLA group, regular rhythm was noted in 11 (58%) of 19 patients on the ECG, and 8 patients (42%) had AF at 12 months after the maze procedure. Sinus rhythm was initially restored in one of these eight patients but reverted to AF at 12 months. In the control group, regular rhythm was seen in 27 (84%) of 32 patients (*p* < 0.05 vs. GLA group). Of five patients (16%) who still had AF at 12 months after the procedure, initially restored sinus rhythm reverted to AF in two. The incidence of persistent AF was significantly higher in the GLA group (*p* < 0.05).

Not all patients with regular rhythm had P waves; one patient in the GLA group and one in the control group who had regular rhythm had no P waves in any ECG lead. Thus, the electrical atrial activity demonstrated by the presence of P waves was resumed in 53% of the patients with GLA and in 81% of those without GLA at 12 months after the procedure. The incidence of P waves in relation to time is shown in Figure 2 and seemed to increase over time. The incidence of P waves in the control group was significantly higher than that in the GLA group throughout the study period.

**Atrial contraction after the maze procedure.** During the follow-up period, atrial contraction was resumed in 4 patients (21%) in the GLA group and 21 (66%) in the control group (*p* < 0.01 vs. GLA group), as demonstrated by a restored Doppler transmitral A wave (≥10 cm/s). The incidence of a restored A wave increased with time in the control group but not in the GLA group (Fig. 2). In addition, the incidence of A



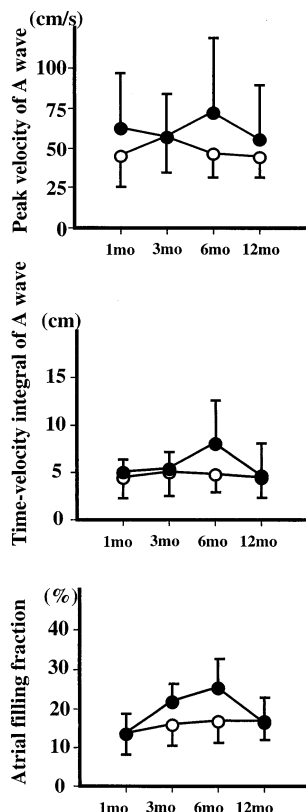
**Figure 2.** Incidence of P waves (left) and A waves (right) in patients with (solid bars) and without GLA (open bars). \* $p < 0.01$ , † $p < 0.05$  versus GLA group.

waves in the control group was significantly larger than that in the GLA group through the study period.

In both the GLA group and the control groups, the peak velocity and time-velocity integral of the A wave and atrial filling fraction appeared to remain unchanged during the study period (Fig. 3). Although we could not statistically analyze these values because of the small number of patients in the GLA group, they appeared comparable between the GLA and the control groups; at 12 months, A wave peak velocities were  $55 \pm 33$  and  $44 \pm 14$  cm/s, time-velocity integrals were  $5 \pm 3$  and  $4 \pm 2$  cm, and atrial filling fractions were  $17 \pm 5\%$  and  $17 \pm 4\%$ , respectively.

The echocardiographic evidence of effective atrial contrac-

**Figure 3.** Temporal changes in peak velocity (top), time-velocity integral of the A wave (middle) and atrial filling fraction (bottom) in patients with restored atrial contraction after maze procedure. Solid circles = GLA group; open circles = control group.



tion was not invariably observed early after the maze procedure. A waves appeared on average  $1.9 \pm 1.4$  months after operation in the GLA group and  $2.7 \pm 2.6$  months in the control group.

**Relation between electrical atrial activity and mechanical atrial activity.** All patients with echocardiographic evidence of effective atrial contraction had P waves on the ECG, suggesting significant electrical activity. However, not all patients with P waves had significant atrial contraction; seven in the GLA group and nine in the control group who had P waves did not have effective atrial contraction. All patients with regular rhythm but without P waves did not show effective atrial contraction.

## Discussion

The maze procedure has been reported to be effective in restoring sinus rhythm in patients with AF with and without underlying valvular disease. We assessed atrial contraction by Doppler transmitral A wave, which represented the actual blood flow to the left ventricle from the left atrium by atrial contraction. Echocardiographic evidence of effective atrial contraction was seen in most patients without GLA. However, fewer patients with GLA could resume effective atrial contraction.

**Effective atrial contraction after the maze procedure.** Sinus rhythm has been reported to return in 67% to 98% of patients after the maze procedure (7,10-12,14). Most previous investigations assessed the effectiveness of the maze procedure by showing the rate of sinus conversion, and only a few studies assessed the degree of atrial contraction by echocardiography (15) or magnetic resonance imaging (8). In the present study, only 66% of patients without GLA and 21% of patients with GLA had restored echocardiographic evidence of atrial contraction. Previous investigations reporting a larger proportion of patients with atrial contraction might consider even a very small A wave as a sign of atrial contraction. Moreover, when the early filling wave and the A wave are partly fused, as is often seen after mechanical mitral valve replacement, A wave velocity measured from baseline overestimates the actual atrial contraction because of the overlapped early filling wave. Thus, we regarded an A wave velocity  $\geq 10$  cm/s as an indicator of echocardiographic evidence of atrial contraction. Feinberg et al. (14) reported that the left atrial filling fraction in patients with restored sinus rhythm after the maze procedure was  $20 \pm 5\%$ . Consistent with their results, the atrial filling fraction of our patients was  $17 \pm 4\%$  in the control group and  $17 \pm 5\%$  in the GLA group at 12 months after operation.

**Restoration of atrial contraction in patients with GLA.** GLA has been empirically recognized as refractory to conventional cardioversion. In the present study, regular rhythm was restored in 58% of patients with GLA at 12 months after the maze procedure. Most of these patients did not show effective atrial contraction possibly because of a fibrotic and calcified degeneration of the left atrial myocardium caused by rheumatic or degenerative mitral valve disease. However, it is



surprising that 21% still had restored atrial contraction. It is also noteworthy that once atrial contraction recovered, the degree of contraction in patients with GLA was comparable to that in patients without GLA. The maze procedure is designed to divide the macroreentry circuits responsible for AF and to direct the electrical wave front from the sinoatrial node to both atria and the atrioventricular node, which may help restore atrial systolic function and sinus regular rhythm. Because the dilated atria could theoretically sustain a macroreentry circuit, we removed the atrial tissue to reduce the size of atria. Very recently, partial left ventriculectomy has been performed in several institutions as a treatment for severe congestive heart failure in patients with dilated cardiomyopathy (Batista's operation) (16,17). It has been proposed that reduction of ventricular wall stress caused by the reduction of ventricular size might improve ventricular wall motion. Reduction of atrial size by the maze procedure may reduce the atrial wall stress and facilitate atrial contraction, as with the left ventricle after Batista's operation.

**Electrical atrial activity versus mechanical atrial activity.** We demonstrated that restoration of electrical atrial activity was not comparable with that of mechanical atrial activity. The electrical atrial activity demonstrated by the presence of P waves was resumed in 53% of the patients with GLA and in 81% of patients without GLA at 12 months after the procedure. However, only 4 patients in the GLA group and 21 in the control group could resume mechanical atrial activity (A wave peak velocity  $\geq 10$  cm/s). Thus, there was discordance between the restoration of electrical atrial activity and mechanical atrial activity. It appears that mechanical activity is more refractory than electrical activity to resumption by the maze procedure.

**Clinical implications.** It is controversial whether the maze procedure should be performed all patients with GLA. However, we showed that P waves were restored in  $\sim 50\%$  of the patients with GLA in whom AF could not be defibrillated otherwise. Furthermore, the degree of atrial contraction was comparable between patients with and without GLA. Kawaguchi et al. (18) reported the risks and benefits of the maze procedure for AF associated with organic heart disease. They have demonstrated that functional capacity improved and cardiac size showed a significant reduction after the procedure without adding operative risks to patients. Accordingly, the maze procedure may be an option in selected patients with GLA if sinus conversion is desirable. However, if patients are at high operative risk, as in the presence of left ventricular dysfunction, the maze procedure may not be appropriate.

Manning et al. (19) reported that in patients with AF, the return of atrial contraction was delayed, and the strength of atrial contraction progressively increased over several weeks to several months after direct current cardioversion. With the maze procedure, surgical damage to the atrial myocardium, such as incision and edema, would delay recovery of atrial contraction. We found that recovery of atrial contraction occurred  $\sim 3$  months after the procedure. Also, the response of the sinoatrial node to exercise after the maze procedure has been reported to be initially blunted but recovers, with an

improvement in exercise capacity at the late phase (20). Thus, electrical and mechanical atrial properties appear to be restored gradually after defibrillation.

**Study limitations.** We did not determine whether the maze procedure can reduce the risk of thromboembolism through the maintenance of sinus rhythm. Most of our patients underwent valve replacement with mechanical valves, requiring long-term anticoagulation, which makes it difficult to assess the effects of the maze procedure on preventing late thromboembolism. Other studies are needed to assess the clinical significance of the maze procedure in relation to reduction of thromboembolic events.

The duration of AF was significantly longer, and left ventricular end-diastolic and postoperative left atrial diameters were larger, in the GLA group than in control group. These factors may affect the low success rate in restoring atrial contraction in the GLA group (21). The control group had a higher incidence of mitral stenosis. In contrast to the large atria with volume due to mitral regurgitation, perhaps the atria with increased left atrial pressure caused by mitral stenosis have more left atrial hypertrophy than left atrial enlargement. Such hypertrophied atria may be more likely to regain effective atrial contraction after sinus conversion.

ECG P waves originate from right atrial activity as well as left atrial activity. However, we evaluated only left atrial contraction, not right atrial contraction, by Doppler echocardiography. Some patients with P waves without significant transmitral A waves might have right atrial contraction demonstrated by transtricuspid A waves. Shyu et al. (22) showed that the mechanical function of the right atrium recovered earlier than that of the left atrium after atrial compartment operation. Nakatani et al. (23) also reported discordance of recovery of right and left atrial contraction after the maze operation. These may partly account for the discordance between electrical and mechanical activity in the present study. Left atrial contraction is more important than right atrial contraction because it relates to maintaining cardiac output, preventing pulmonary congestion and preventing systemic thromboembolism. Thus, we measured only left atrial contraction in the present study.

**Conclusions.** We serially assessed atrial contraction after the maze procedure in patients with and without GLA by means of Doppler echocardiography. Although electrical activity could be restored in most patients without GLA, fewer patients with GLA had restored atrial contraction. However, in patients with GLA,  $\sim 50\%$  showed electrical activity, and only 21% of patients had restored effective atrial contraction. However, once atrial contraction was resumed, the degree of contraction was comparable with that in patients without GLA. Therefore, the maze procedure may be an option in selected patients with GLA.

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